Z-Pinch EUV Power Scaling *

Intro: PLEX LLC

Z-Pinch rationale

Results to date

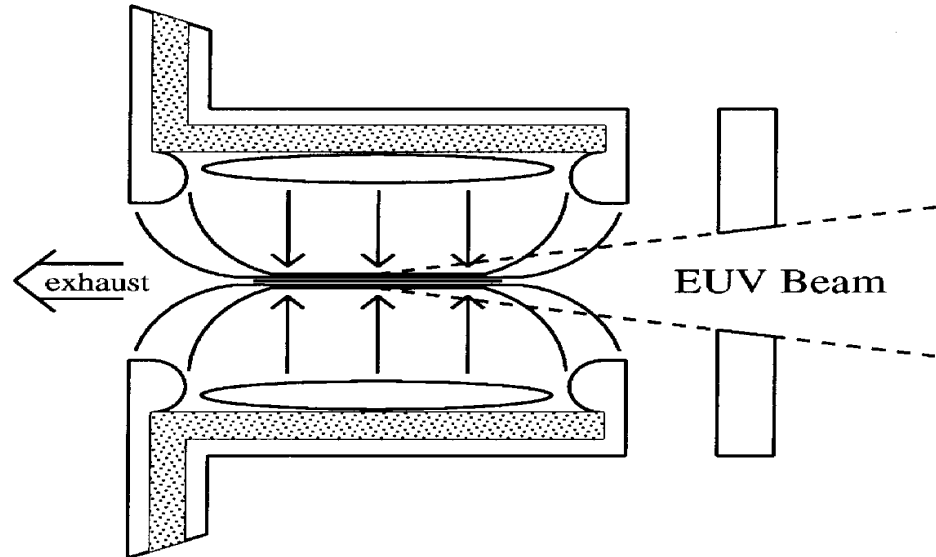Repetition Rate Scaling Schedule

DARPA Program

Condenser for Z-Pinch

Cost of Ownership

Talk presented by Malcolm McGeoch on 10-12-99*.   Contact mcgeoch@xuv.com

* data previously published in Proc. SPIE Vol 3676 pp697-701 (1999) is not repeated in this electronic version of the talk. The 10-12-99 presentation is updated to include 100Hz results up to 11-20-99.

Z-Pinch Chosen Because:

1. EUV production requires hot (20-50eV) plasma which causes erosion by sputtering and melting when close to any surface.

   <u>Inertial</u> Z-pinch has plasma at 10-15mm from nearest surface.

   Expanding plasma cools (radiatively) before striking surface. Radial motion is also braked by magnetic field, with return of energy to circuit.

2. Direct conversion of electric to plasma energy is potentially very efficient. (e.g. 20% radiation efficiency into whole EUV xenon band)

Z-Pinch Results to Date (11/20/99)

10^6 pulse test at 340J stored showed very low erosion rate in liner and electrodes. Life extrapolates to >5x10^7 pulses under this load (0.87 J cm^{-2} on liner). (250Hz tests at 100J stored will use 0.5J cm^{-2}).

Debris emission is low

EUV power 1.8W (0.10 sr, 3% BW at 134.5A, 100Hz)

Repetition rate to 100Hz

Strongest emission is at 134A and 108A
Z-Pinch spectrum is ideal for Mo-Si optics, but usable for Mo-Be

Pulse-to-pulse amplitude stability at 100Hz (134A) 3% rms
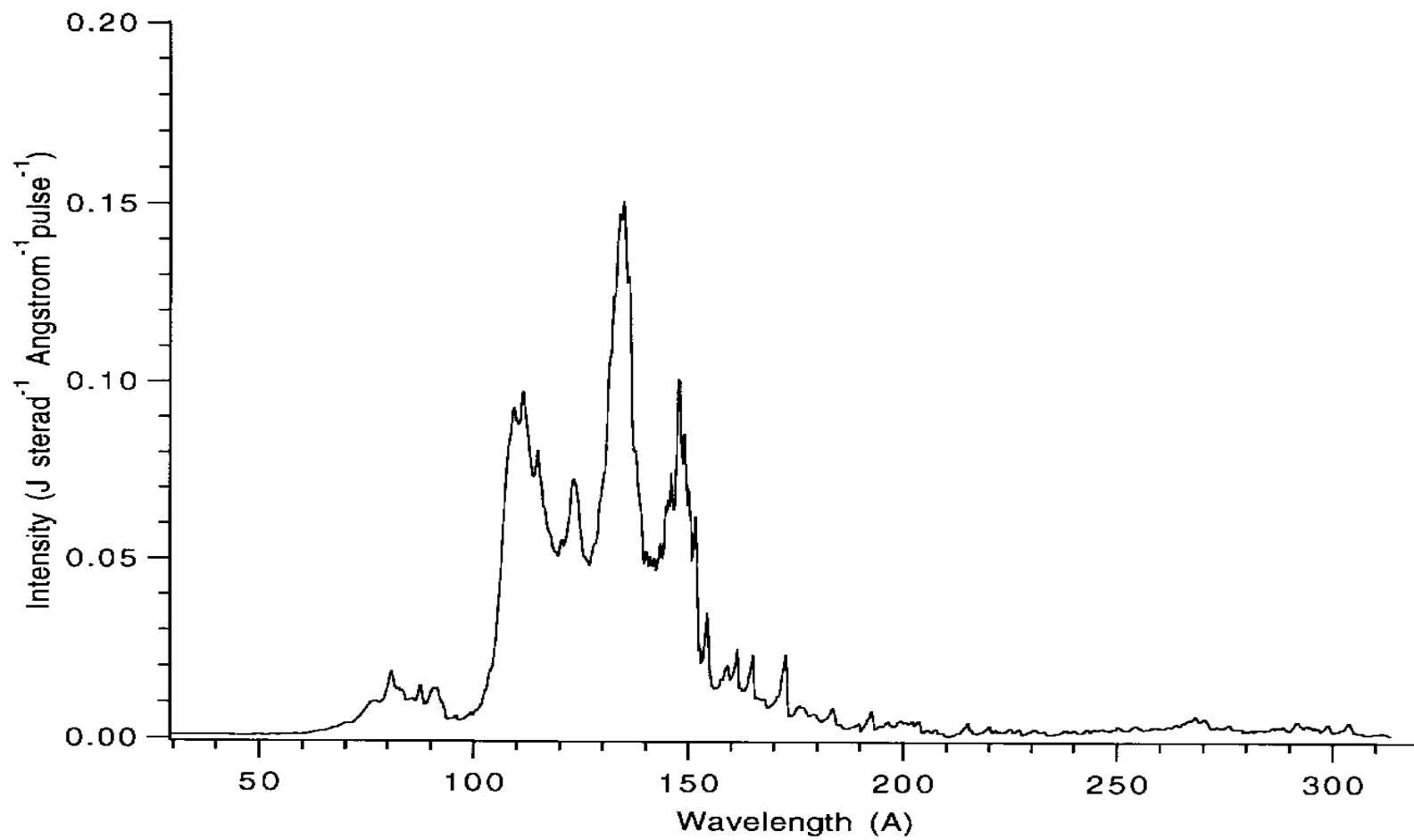
Transverse positional stability ±50µm absolute

Source size 0.19cm (Gaussian 1/e intensity radius)

Liner heat load understood, hydrodynamic/radiative modeling and experiment

Axial radiation intensity for three rare gases
240J stored (4cm pinch, precursor machine)
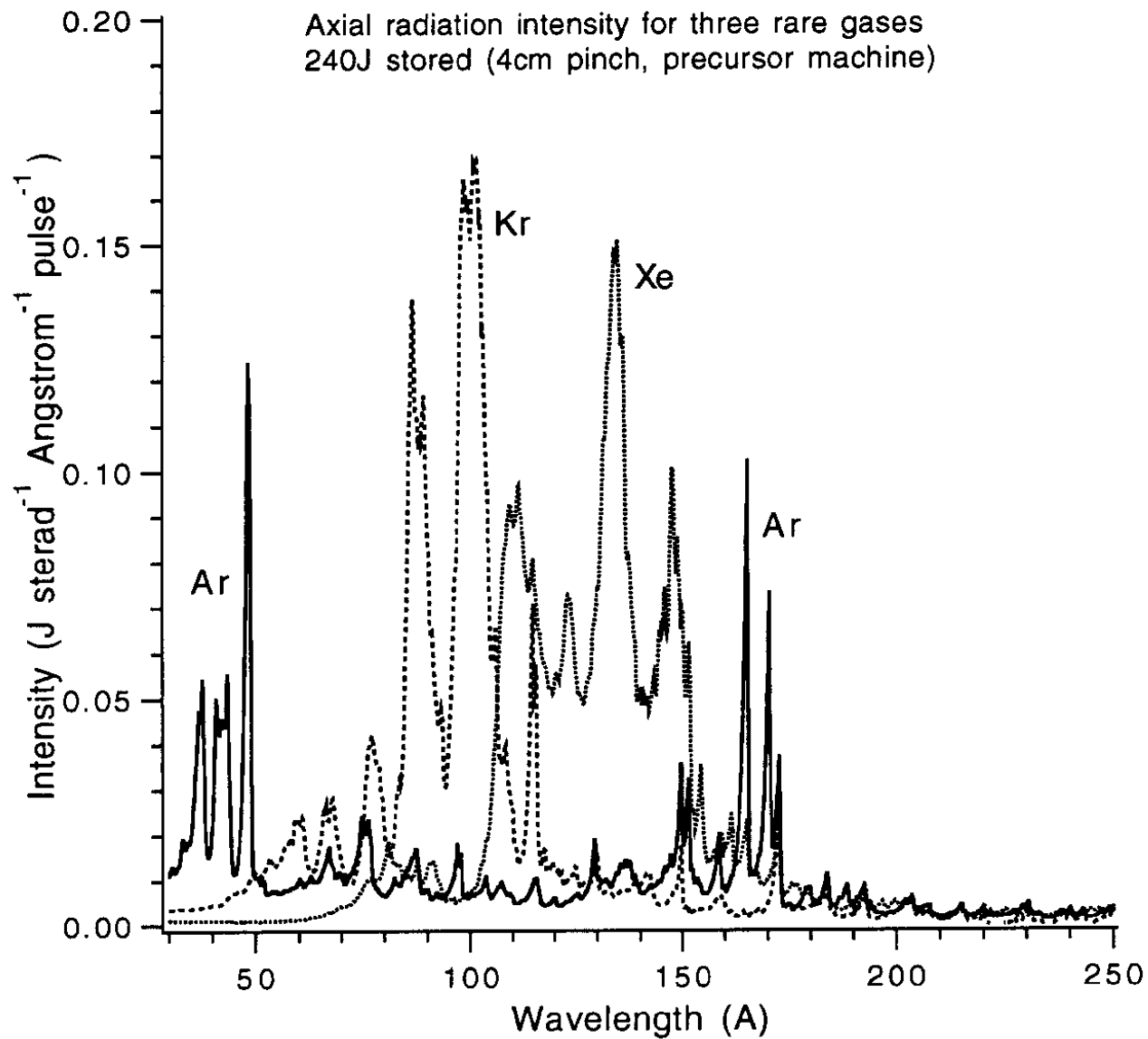
Xenon band spectrum, 4cm Z-pinch, 240J stored

PLEX Z-Pinch Development Schedule

Parameter (all at 13.4nm)	Status(1-31-99)	Status(11-19-99)	Goal(1-31-00)	Goal(1-31-01)
EUV power (W/2πsr)(2.5% BW)	35	95	250	1,000
Pulse energy (J/2πsr)(2.5%BW)	3.5	0.95	1.0	1.0
Repetition rate (Hz)	10	100	250	1,000
Solid angle of beam (sr)	0.03	0.10	0.10	0.12
Power (W) into SA (2.5% BW)	0.17	1.5	4.0	16
Electrical power (kW)	3.5	10	25	60
Source diameter (mm) (1/e)	3.0	3.8	3.5	3.5
Source length (mm)	60	25	25	25
Source amp. stability (%rms)	2	3	2	2
Source transverse stability (μm)	35	50	35	35
Liner heat load (Wcm^{-2})	10	50	125	400
Liner average wall temperature (C)	40	90	185	540
Liner/electrode life (pulses)	$\gg 10^6$	$\gg 10^5$	10^8	10^9
Switch type	Thyratron	Thyr.	Thyr.	Solid state
Xenon flow	Exhaust	Exhaust	Closed loop	99% recovery
Debris characterization	$\gg 10^5$	-	$\gg 10^7$	10^9

DARPA/PLEX program

1st year (6-99 --> 6-00)

Perform several 10^7 pulse runs at 100J stored, 250Hz. Measure component erosion. Measure EUV reflectance of mirror exposed during runs.

Cost share: PLEX 20%, US Govt. 80%, Total $538K

Optional 2nd year (6-00 --> 6-01)

Perform at least one 10^8 pulse run at 60-100J stored, 1,000Hz. Measure component erosion. Measure EUV reflectance of mirror exposed during run. Solid state magnetic modulator.

Cost share: PLEX 50%, US Govt. 50%, Total $872K

Condenser for Z-Pinch Source

Large source size allows comfortable critical illumination design with only two types of reflecting element, both spherical concave.
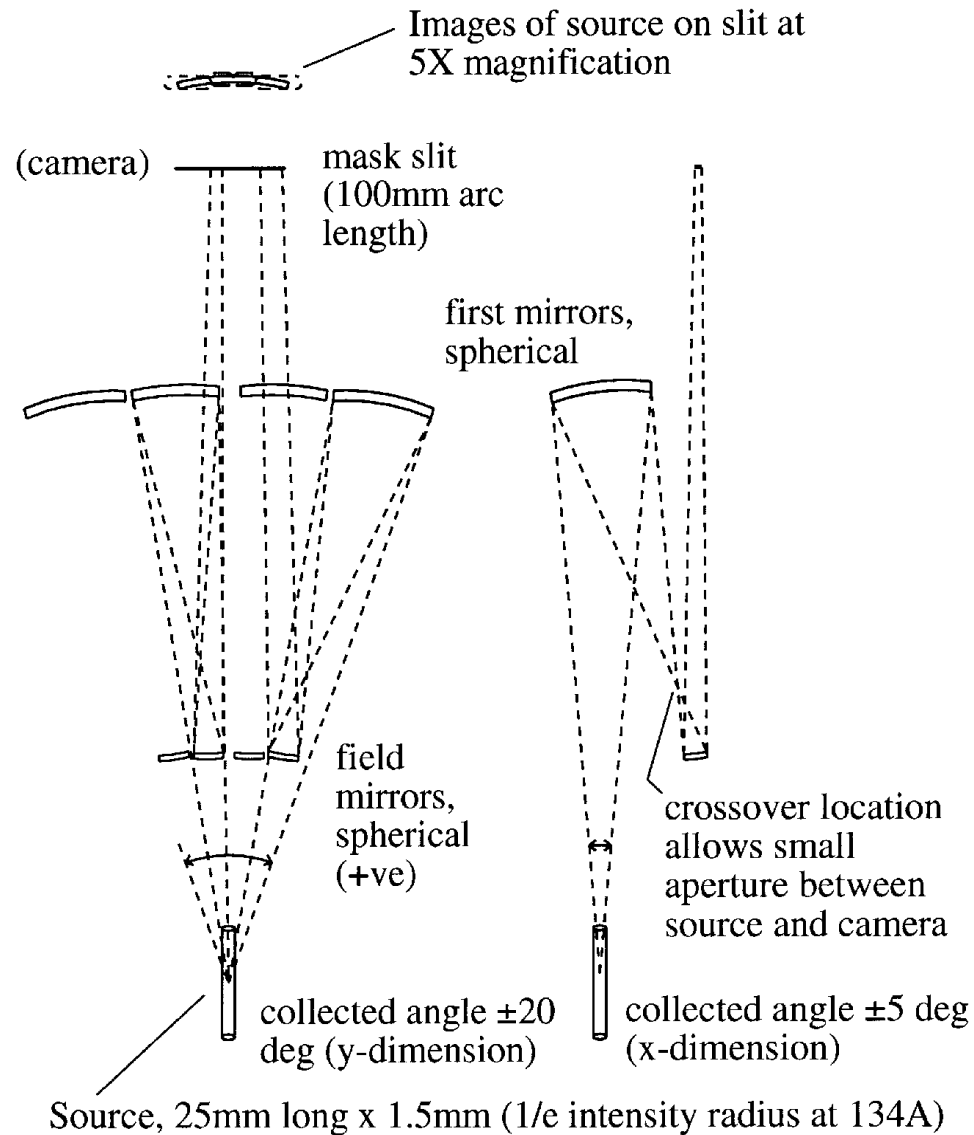
Measured Z-pinch size at 13.4nm can match x-dimension etendue of test camera (0.21 mm rad) with 43% capture efficiency in this dimension. X-dimension collection range is ±5 deg.

Y-dimension etendue of test camera (3.5 mm rad) allows collection up to ±20 deg. Efficiency in y dimension is 60% after intensity is made uniform parallel to mask slit.

Overall efficiency of transfer into mask slit is 9% for EUV LLC test stand camera. Transfer efficiency improves as camera etendue increases.

1kHz projection: 12W in 2.5% BW at 13.4nm, into collection solid angle of 0.12sr implies 1.1W into test stand mask slit.

Condenser: Critical illumination

Images of source on slit at 5X magnification

(camera) — mask slit (100mm arc length)

first mirrors, spherical

field mirrors, spherical (+ve)

collected angle ±20 deg (y-dimension)

crossover location allows small aperture between source and camera

collected angle ±5 deg (x-dimension)

Source, 25mm long x 1.5mm (1/e intensity radius at 134A)

Uniform illumination requires intensity
adjustment of central images, and probably
apodisation at edges of mask aperture

image of source

mask aperture

1/2 intensity contour

"x"

"y"

intensity   attenuation
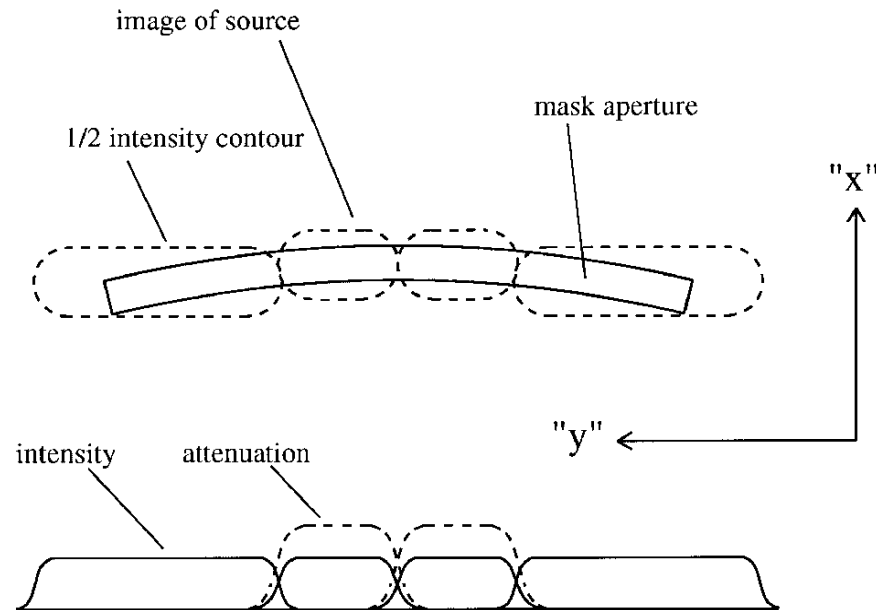
Future increase in camera etendue will
alleviate apodisation requirement, and
improve condenser efficiency

Z-Pinch Cost of Ownership

Assumptions: 1kHz; 12W in 0.12sr, 2.5%BW, 134A; 65% duty
Liner replacement each 10^9 pulses
Electrode replacement each 10^9 pulses
99% xenon recovery

	Annualized
Capital cost $750,000 amortized over 5 years	150,000
Consumables:	
xenon	5,000
electricity	10,000
solid state switch stacks each 10^{10} pulses	75,000
capacitor set each 10^{10} pulses	14,000
RF preionizer modulator each 5 years	1,600
vacuum pump each year	9,000
power supplies each 5 years	7,000
pinch ceramic liner each 10^9 (18 days at 65%)	4,000
pinch electrodes each 10^9	10,000
service labor 4man hrs/wk at $100 per hr.	20,000
	305,600

Cost per <u>billion</u> pulses = $15K, of same order as excimer laser

Conclusions

The Z-pinch approach to EUV generation can (in principle)
be scaled to meet industrial power and life requirements

100Hz operation. Tests at up to 250Hz are scheduled to occur within
the next two months

Cost of Ownership is expected to be comparable to present day
excimer sources

The condenser for the Z-pinch promises to be much simpler than
that for sources that collect a larger solid angle of light

The low solid angle beam allows easy deployment of
foil trap or gas blanket debris shields, if needed